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IMPLEMENTATION OF SURFACE DETECTOR OPTION IN SCALE SAS4 SHIELDING MODULE

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The Shielding Analysis Sequence No. 4 (SAS4) in the Standardized Cask Analysis and Licensing Evaluation System (SCALE) is designed to aid the novice user in the preparation of detailed three-dimensional models and radiation protection studies of transportation or storage packages containing spent fuel from a nuclear reactor facility. The underlying methodology in these analyses is the Monte Carlo particle-tracking approach as incorporated into the MORSE-SGC computer code. The use of these basic procedures is enhanced via the automatic generation of the biasing parameters in the SAS4 sequence, which dramatically increases the calculational efficiency of most standard shielding problems. Until recently the primary mechanism for dose estimates in SAS4 was the use of point detectors, which were effective for single-dose locations, but inefficient for quantification of dose-rate profiles. This paper describes the implementation of a new surface detector option for SAS4 with automatic discretization of the detector surface into multiple segments or subdetectors. Results from several sample problems are given and discussed.

KEYWORDS: Spent fuel cask, radiation protection, dose rate analysis, surface detectors

1.0 Introduction

The Standardized Cask Analysis and Licensing Evaluation System (SCALE) [1] was developed by the Oak Ridge National Laboratory to solve a wide variety of problems corresponding to nuclear criticality, radiation shielding, spent-fuel source-term generation, and heat-transfer applications. The Shielding Analysis Sequence No. 4 (SAS4) is designed to automate the radiation protection analysis of a transportation or storage package containing spent fuel from a nuclear reactor facility. Previous versions of SAS4 have relied primarily on point detector estimates of the dose rates at specific locations around the cask body. A surface detector option was available for SAS4, but with very severe limitations. Each surface detector contained only a single segment that was primarily useful only in obtaining average dose rates over large surfaces, typically the entire cask height or radius. This limitation has been removed in SCALE 4.4.

The surface detectors in SAS4 can now be broken into *segments* or subdetectors, each of which is separately reported. These surface detectors are cylindrical in shape, with up to 400 spatial (i.e., axial segments along a cask side, or radial segments along the cask top or bottom) subdetectors and an unlimited number of azimuthal subdetectors possible.

These subdetectors allow for radial, azimuthal, or axial profiles to be easily and efficiently generated. As with any surface detector option, the smaller the area of the surface detector, the larger the number of particles that should be tracked to achieve acceptable statistics. These surface detectors are useful when the full dose-rate profiles are desired, whereas the generation of dose rates at a large number of point detectors is very inefficient. Thus, for a large number of realistic problems, this enhanced surface detector option in SAS4 is expected to be much more efficient than the previously available point detector capability. Note that a similar study was previously reported,[2] which described an updated version of SAS4, termed SAS4A. The work described in this paper was initially performed in collaboration with that work; however, the final phases of the work were performed independently. The version described herein is available for public release in SCALE 4.4, while the other version is not scheduled for release.

2.0 Code Implementation

Surface detectors are analog detectors that calculate averaged responses based on particles crossing the detector surfaces. Subroutine BDRYX is called whenever a particle crosses a surface and is thus instrumental in the determination of doses along a surface. Thus, the major changes in the coding to add the additional surface detector capability were in the BDRYX subroutine. These changes included increasing the size of the array containing the surface detector results. It was also necessary to change the storage order of the point detector and surface detector information. Other peripheral subroutines had to be updated to read the extra input and produce output for the extra detectors.

Under this new surface detector option, four surface detectors are automatically implemented for the simplified geometry input; under the full MARS

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geometry option (IGO = 4), the user may input up to 36 surface detectors. Depending on the direction of the transport calculation indicated by the IDR parameter (IDR = 0 for radial calculation and IDR>0 for an axial calculation), the surface detectors are located radially or axially on the outermost surface of the cask and on three other cylinders outside the cask. With the latest enhancements in SAS4, the user can specify the locations of the surface detectors and divide each surface into spatial and angular subdetectors.

The axial surface detectors are circular disks arranged symmetrically on and beyond the top and bottom ends of a cask. Flux estimates are made on both sets of the disks, and the averaged responses are computed for each detector in the Monte Carlo analysis. The default locations of the axial surface detectors are the outermost cask surface and 1, 2, and 3 m from this surface. The default radii of the axial surface detectors are RCAV cm for the first detector and (RCAV + 100) cm for the other three detectors, where RCAV is the radius of the cavity. The user can override the locations and limits of the surface detectors using the SDL and SDR input arrays respectively (see Table 1). In Fig. 1, the default top axial detectors are shown and labeled as detectors 1a through 4a.

Table 1. Surface detector array input requirements

SDL, ((SLOC(I)),I=1,ISD), END - Begins with the keyword SDL and ends with the keyword END, SLOC(I) is the location of the surface detector I, where SLOC(1) must have the smallest value. For radial calculations (i.e., IDR **=** 0) SLOC are the radii of the surface detectors. For axial calculations SLOC are the heights of the surface detectors. The default values are RJAC, RJAC + 100, 322, and 358 for radial calculations; and HIM1, HIM1 + 100, HIM1 + 200, and HIM1 + 300 for axial calculations. For radial calculations, if RJAC is greater than or equal to 222, the user must input SLOC array. For IGO<4, ISD must be 4 and there can be no more than 3 surfaces outside the cask and SLOC(1) is set to RJAC or HIM1 by SAS4. For IGO = 4, ISD can be any value ≤36. Each value in the array must correspond to a surface in the geometry input by the user. If not input, the same four default surfaces are used.

SDR, ((ZRMIN(I), ZRMAX(I),I=1,ISD), END - Begins with the keyword SDR and ends with the keyword END. ZRMIN(I) is the lower limit of the surface detector I, and ZRMAX(I) is the upper limit of the surface detector I. For radial calculations ZRMIN and ZRMAX are the lower and upper limits in the axial direction. The user is reminded that ZRMIN must be ≥0.0, with Z = 0.0 being the cask axial midplane. For axial calculations ZRMIN, and ZRMAX are the limits in the radial direction. The default values for ZRMIN are 0.0 for all surfaces. However, for ZRMAXs, the default values are HFUE for the first surface, and HFUE + 100 for the other three surfaces when IDR = 0; and RCAV for the first surface, and RCAV + 100 for the other three surfaces when IDR>0. When ISD is greater than 4, this array must be input. Users are advised to define these limits to be slightly different from the actual geometric boundaries in order to avoid round-off problems.

SDS, ((INTZR(I), INTAM(I),I=1,ISD), END - Begins with the keyword SDS and ends with the keyword END. INTZR(I) is the number of equal-size subdetectors between ZRMIN(I) and ZRMAX(I) for the surface detector I. INTAM(I) is the number of equal-size subdectors in the azimuthal direction for surface detector I. The value of INTZR cannot be greater than 400, but the value of INTAM has no upper limit. The user should exercise reasonable judgement in selecting the input values. The default values for INTZRs and INTAMs are 1.

The radial surface detectors are side surfaces of cylinders having appropriate radii. The default locations of the radial surface detectors are: RJAC cm, (RJAC + 100) cm, 322 cm, and 358 cm, where RJAC is the radius of the outermost side surface of the cask. The radial locations of 322 cm and 358 cm correspond to 2 m from the edges of a truck bed and a rail car respectively. If RJAC is ≥222, the SDL array must be used to specify the locations of the radial surface detectors. The reason for this requirement is that (RJAC + 100) would be greater than 322, which will cause a geometry error in MORSE-SGC. The default heights of the radial surface detectors are 2* HFUE cm for the first detector and 2*(HFUE + 100) cm for the other three detectors, where HFUE is the height of the active fuel measured from the midplane of the cask. The default radial surface detectors are shown in Fig. 1 as detectors 1b through 4b. Similarly, the SDL and SDR input arrays can be used to change the locations and limits of the radial surface detectors.

Because of the method of particle tracking used with MARS[1] geometry, a surface detector must be part of a surface between two different media or two different importance regions. In the geometries automatically generated by SAS4 for the simplified geometry input option (IGO≤3), the four default surface detectors (radial or axial) are located on surfaces between different importance regions. Using the simplified geometry option, the surfaces of the impact limiters (top and bottom) are the outermost axial surfaces of the cask, and the surface of the

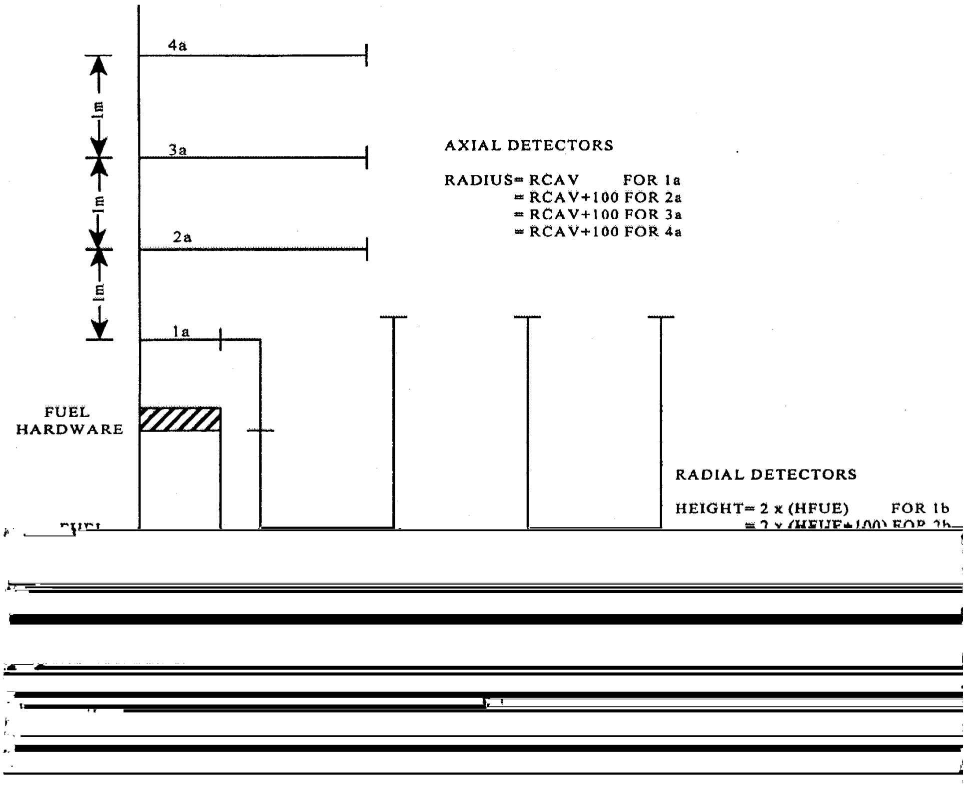

Figure 1. SAS4 default axial and radial surface detectors (only top half is shown).

water jacket is the outermost radial surface. Thus, the axial or radial surface doses are scored on these surfaces and on surfaces exterior to the cask. For the full MARS (IGO = 4) geometry option, the user must make sure that the scoring cylinders are in the geometry and that their dimensions can accommodate the limits of the surface detectors. Under the IGO = 4 option, up to 36 surface detectors are allowed and the surface detector locations can all be outside the cask as long as each detector location corresponds to a surface in the geometry.

3.0 Results

This section describes results from using the new SAS4 surface detector capabilities for several spent-fuel cask problems. The first case consists of a full-size cask containing 32 PWR fuel assemblies in a smeared basket arrangement. An XY plot of the cask at its axial centerline is shown in Fig. 2. This case used 6 different surface detectors, with some 5000 subdetectors. The number of subdetectors was generally 20–30 in the axial direction and 36 in the azimuthal direction for each of the 6 surface detectors. This large number of subdetectors is not typical for a standard analysis, but was executed in this manner as a demonstration of the capabilities of the newly updated coding. This problem is further described in the SCALE manual and is identified as Sample Problem 9. This configuration was analyzed with the problem input specifying 80 batches of 4000 particles each. The CPU time for this problem was 86 minutes on an IBM RS/6000 Model 580 computer. The Monte Carlo statistics for the 6 surface detectors were generally in the 1–2% range, which correspond to an average dose over both the azimuth and axial subdetectors. Statistics for the axial subdetectors (i.e., axial profiles averaged over the azimuths) were generally in the 3-7% range for each of the 20–30 axial segments (see an example in Fig. 3). Azimuthal subdetectors produced statistics in the 10–30% range for each of the 36 azimuthal and 20–30 axial segments (see Fig. 4 for the azimuthal variation in one axial segment). While the azimuthal subdetectors need more particles to produce acceptable statistics, this example shows the power of the flexible surface detector option in SAS4. The

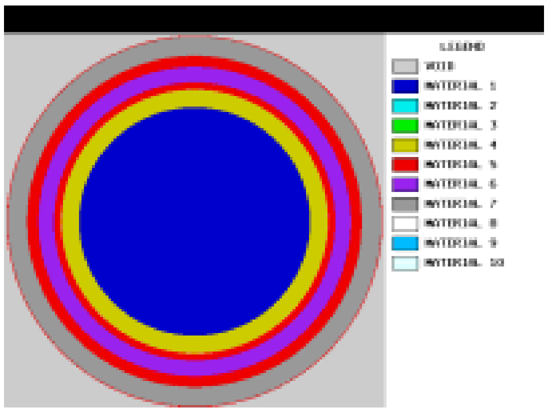

Figure 2. XY plot of axial centerline for problem No. 1 cask.

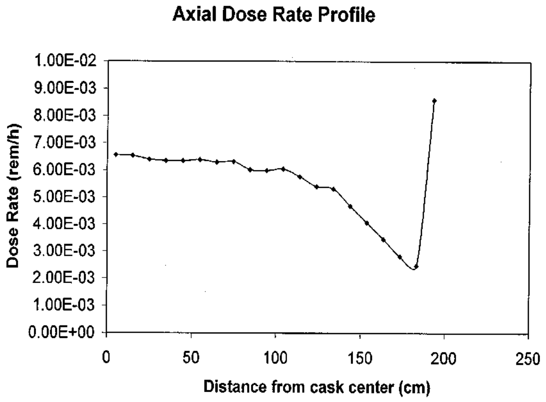

Figure 3. Axial neutron dose rate (rem/h) profile along outermost surface of problem No. 1 cask.

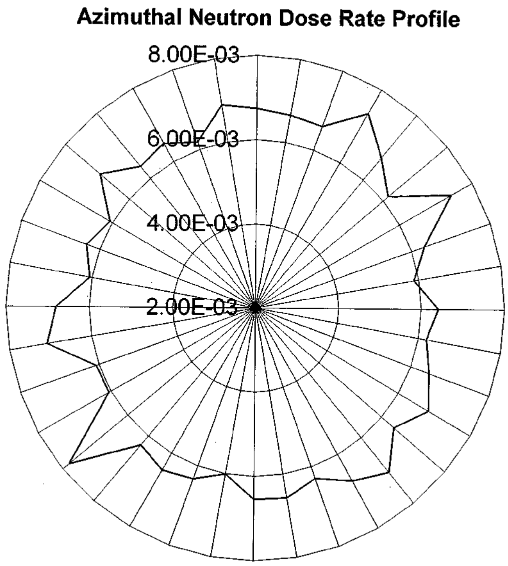

Figure 4. Azimuthal neutron dose rate (rem/h) profile near axial midplane for problem No. 1 cask.

cost to generate results for this number of point detectors in SAS4 would have been prohibitive.

Since the preceding problem only contained solutions for neutrons, a second problem that contained solutions for both neutrons and gamma-rays was desired. The selected problem was taken from a previous study[3] which analyzed a series of measurements for 5 storage casks loaded with spent fuel. Each of these casks require multiple inputs to completely describe the results. Two of these inputs from a single-cask case were analyzed using the new surface detector capabilities in SAS4. The cases correspond to the MC-10 cask configuration with neutron and gamma results from the "r-type" assemblies only. For neutron calculations there were 9 r-type fuel assemblies; for gamma calculations, only 8 r-type fuel assemblies were modeled. The loading patterns for both neutrons and gammas are given in Fig. 5. It is clear from these loading patterns that, unlike the preceding problem, the dose rates should not be azimuthally symmetric. The surface detectors for these problems consisted of 5 axial subdetectors and 48 azimuthal subdetectors. The standard deviations for these results were typically less than 1% for the azimuthal- and axial-averaged values, and 3–6% for the individual azimuthal and axial values. The neutron case used 1000 batches of 2000 particles and ran in 100 minutes, while the gamma case used 100 batches of 5000 particles and ran in 48 minutes. Both execution times correspond to a DEC Alpha Station 500 machine. The results for the two cases are shown in Figs. 6 and 7, respectively for neutrons and gammas. The neutrons clearly tend to smooth out the azimuthal variations due to the tendency to scatter over large angles, while the variations in loadings are very distinct from the gamma results.

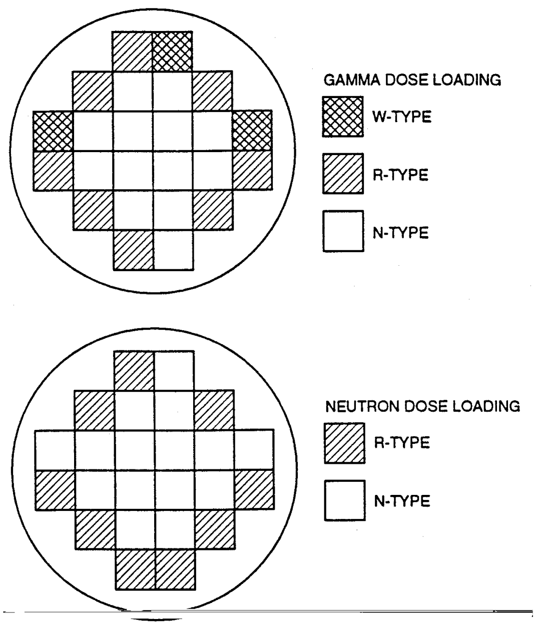

Figure 5. Loading pattern for MC-10 cask.

4.0 Conclusions

The set of results presented is designed to illustrate the capabilities of the updated surface detector options in the SAS4 code. The surface detector results show that a great deal of flexibility is now possible in the analysis of storage/transport casks containing spent fuel. Profiles showing variations in dose rates in either the azimuthal or axial directions are now very easy and efficient to produce, using the currently released version, SCALE 4.4. Similar SAS4 capabilities have been reported, but are not available for wide distribution, as is the SCALE package.

Azimuthal Neutron Dose Rate Profile

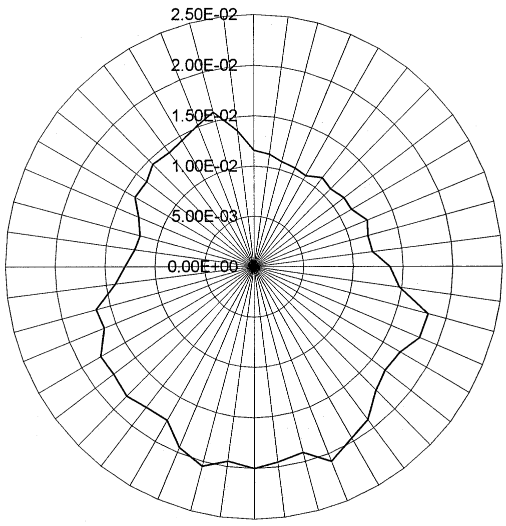

Figure 6. Azimuthal neutron dose rate (rem/h) near axial midplane of MC-10 (r-type assemblies only) cask.

Azimuthal Gamma Dose Rate Profile

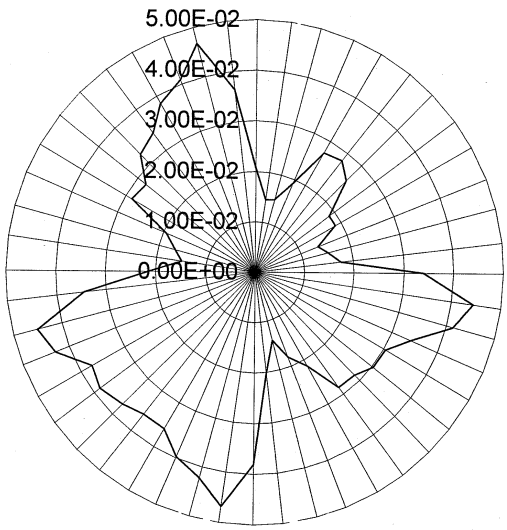

Figure 7. Azimuthal gamma dose rate (rem/h) near axial midplane of MC-10 (r-type assemblies only) cask.

5.0 References

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